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Intraoperative duplex ultrasound of visceral revascularizations: Optimizing technical success and outcome

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Purpose: **The purpose of this study was to evaluate the use of intraoperative duplex ultrasound scanning (IOUS) during visceral revascularizations and correlate its results with clinical outcome.**
Methods: **We studied 68 patients (15 men and 53 women, mean age 66.5 years, range 27-86 years) who underwent visceral revascularization with concomitant IOUS examination of 120 visceral arteries (52 celiac, 60 superior mesenteric, and 8 inferior mesenteric arteries) from 1992 to 2002. Patients were divided into two groups on the basis of ultrasound findings: normal and abnormal IOUS. The incidence of early and late graft-related complications (thrombosis, restenosis, recurrent symptoms, reintervention) and graft-related death was compared in both groups.**
Results: **One-hundred and two (85%) arteries had normal IOUS. Eight (6.6%) arteries had minor defects, including small kinks (4), mild residual stenoses (3), and small intimal flap (1). Ten (8.4%) arteries had major defects, consisting of hemodynamically significant residual stenoses (4), thrombus (2), kinks (2), bidirectional flow (1), and intimal flap (1). Major defects were successfully revised in all except three cases: two persistent mild stenoses and one bidirectional flow. Patients with abnormal IOUS at the end of the operation had increased incidence of graft-related complications and/or death (55.5% vs 7.8%; $P = .004$), early graft thrombosis (14.2% vs 1.0; $P = .04$), reintervention (21.4% vs 3.2%; $P = .03$), and graft-related death (33.3% vs 1.9%; $P = .02$), compared with patients with normal IOUS.**
Conclusion: **This study supports the routine use of IOUS during visceral revascularizations to optimize technical success and outcome. Persistent ultrasound scanning abnormalities are associated with risk of early graft failure, reintervention, and death. Patients with normal ultrasound scans can expect excellent results. (J Vasc Surg 2003;38:684-91.)**

The absence of technical problems is a prerequisite to durable success of arterial reconstructions. Technical failure constitutes the most frequent cause of early thrombosis after revascularization and endarterectomy. The consequences of acute thrombosis of the mesenteric arteries can be disastrous. A residual plaque, stenosis, intimal flap, dissection, or kink after visceral revascularization can result in bowel necrosis with a threat to the patient's life, need for extensive bowel resection, and long-term parenteral nutrition. The aim of intraoperative monitoring techniques is to identify technical problems that need to be immediately revised to prevent early and late failure of the arterial reconstruction.

Immediate correction of major technical defects has been shown to prevent severe early complications and contribute to long-term success after carotid endarterectomy and renal and infrainguinal arterial reconstructions.[1-11] However, the impact of intraoperative ultrasound scan monitoring during visceral revascularizations has not been well documented because of the small number of patients in these series. The purposes of this study were to evaluate the use of intraoperative duplex ultrasound scanning (IOUS) in patients undergoing visceral revascularizations and to correlate its results with the incidence of graft-related complications and graft-related death.

PATIENTS AND METHODS

Using the Mayo Clinic database, we identified 125 patients who underwent visceral arterial revascularization between January 1, 1992 and January 1, 2002. From this group, 68 patients (54.4%) who had concomitant IOUS were included in this study. Demographics, clinical characteristics, and operative data were collected from the patients' records. Early and late medical and surgical morbidity and mortality were recorded. Late follow-up data were obtained from medical records, office visits, correspondence with referring physicians, and telephone interviews. The study was approved by the clinic's institutional review board.

Scanning technique. After completion of the revascularization, IOUS was performed by a staff radiologist assisted by an ultrasound scanning technician. We used an *Acuson* XP 128 or *Sequoia* 512 (Acuson Inc., Mountain View, Calif) duplex ultrasound with 6-15-MHz linear array probes. The initial examination averaged 5 to 15 minutes

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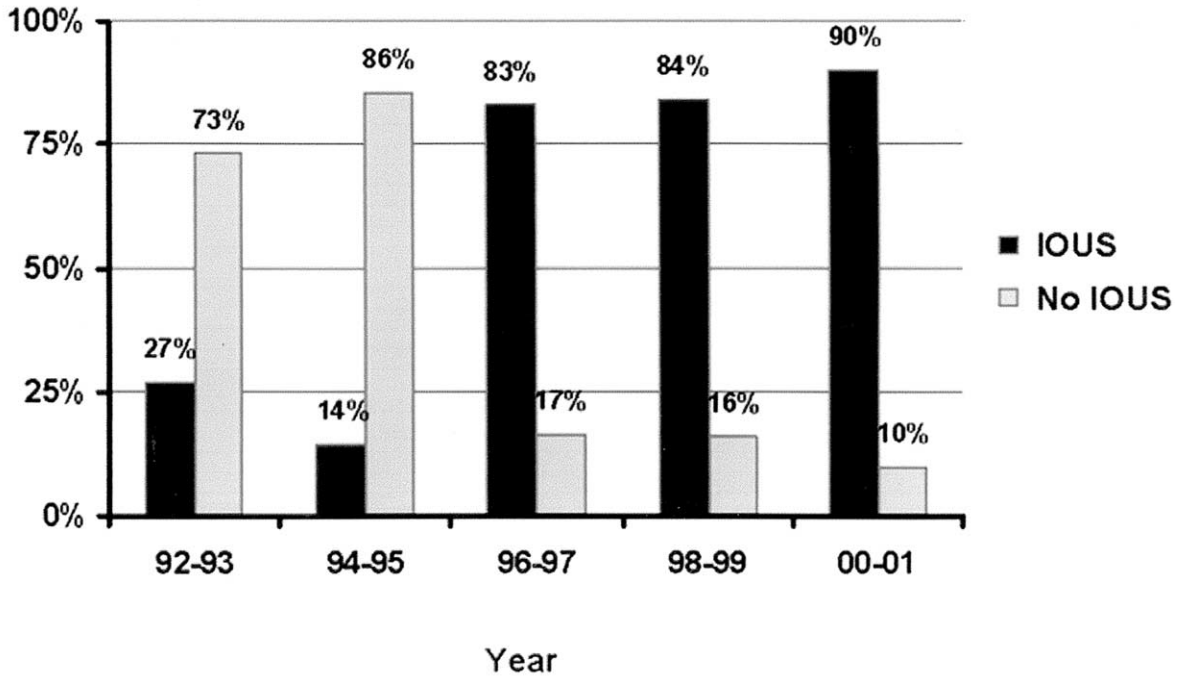

Fig 1. Intraoperative duplex ultrasound has been used since the early 1990s, initially in selected cases (weak pulse or low flow) and later routinely by most surgeons. Since 1996, more than 80% of the patients had intraoperative duplex ultrasound during visceral revascularizations for chronic mesenteric ischemia.

with additional time needed when a technical problem was identified. The probe was placed in a sterile plastic sheath previously filled with acoustic gel. Normal saline solution was poured into the abdominal cavity for acoustic coupling between the probe and the vessel. The probe was positioned at 1 to 2 cm from the vessel for optimal imaging and resolution. We scanned the graft and endarterectomized artery from the aorta to the segment distal to the reconstruction, the proximal anastomosis, the whole length of the graft, the distal anastomosis, and adjacent native arteries. Scanning was performed in the longitudinal and transverse planes with a 60° angle of insonation. The areas of interest were studied by gray-scale and color-flow imaging, followed by Doppler spectral analysis and measurement of peak systolic velocities (PSV), end diastolic velocities (EDV), and velocity ratio ($Vr = PSV_{at\ lesion} - PSV_{proximal}$). Representative centerstream velocity spectra were obtained in areas that had color Doppler flow abnormalities (eg, residual stenosis, increased velocity, color-flow jet).

Indications for intraoperative duplex ultrasound scanning. IOUS was used mostly during revascularizations for chronic mesenteric ischemia. In the early 1990s, ultrasound scanning was used selectively for high clinical suspicion (weak pulse or low graft flow) or complex revascularizations (eg, visceral endarterectomy). Since 1996, most surgeons in our division have adopted routine IOUS (Fig 1). Forty-two of the 60 patients with chronic mesenteric ischemia represent consecutive cases operated by surgeons who have adopted routine IOUS in their practice.

Ultrasound scanning review and classification. Hard copies of all IOUS containing images, spectral analysis, and velocity measurements were reviewed by two staff radiologists (T.A.M., R.L.) who were blinded to the initial examination's result and patient's clinical outcome. Videotapes were not available for review. Ultrasound scanning results were classified into normal and abnormal. A *normal* ultrasound scan had a PSV of less than 2.0 m/sec for the celiac and less than 2.75 m/sec for the superior mesenteric artery (SMA), Vr less than 2.0, and no technical defect (ie, vessel narrowing, thrombus, intimal flap, kink, turbulence, or dissection).[12] Nonfocal PSV elevation without evidence of technical defect was attributed to hyperdynamic state or graft-vessel mismatch and was considered a normal finding. Abnormal ultrasound scans included minor or major arterial defects. *Minor defects* consisted of arterial abnormalities with normal velocities and Vr, including mild-to-moderate residual plaque, small intimal flap (<2 mm), or kinks. *Major defects* consisted of hemodynamically significant (elevated or dampened velocities or elevated Vr) arterial abnormalities, including significant residual stenosis, thrombus, intimal flap, dissection, turbulence/kink, or abnormal flow (decreased, reverse, or bidirectional flow). Major defects prompted immediate operative revision. The radiologist review concurred with the intraoperative interpretation in all except five cases of graft-vessel mismatch not described in the initial report.

Endpoints. On the basis of a final IOUS result, patients were assigned to one of two groups for analysis of

Table I. Clinical characteristics in 92 patients who underwent visceral revascularization for chronic mesenteric ischemia (with and without IOUS) during the study period

Variable	*IOUS*		*No IOUS*	
	%	*n = 32*	*%*	*n = 60*
Demographics				
Mean age		68.0		64.6
Percent > 70 years-old	10	16.6	8	25.0
Male gender	13	21.6	7	21.8
Risk factors				
Hypertension	40	66.6	18	56.2
Diabetes	9	15.0	8	25.0
Hyperlipidemia	28	46.6	10	31.3
Tobacco use	43	71.6	21	66.6
CAD	24	40.0	11	34.0
Renal failure	4	6.6	2	6.0
Operative variables				
Previous visceral revascularization	4	6.6	3	9.0
Bifurcated grafts	44	73.3	22	68.7
Visceral endarterectomy	7	11.6	3	9.0
Antegrade bypass	48	80.0	25	86.0
Low flow (<500 ml/sec)	13	21.6	7	21.8

Differences were not statistically significant ($P > 0.05$).
IOUS, Intraoperative duplex ultrasound scanning; *CAD,* coronary artery disease.

clinical outcome: normal or abnormal IOUS. Patients with arterial defects on first IOUS, but normal findings after revision, were assigned to the normal group. Patients with visceral aneurysms, acute ischemia, or medial arcuate ligament syndrome were excluded from the analysis of clinical outcome. Data were compared with the results of 32 patients who underwent visceral revascularization for chronic mesenteric ischemia *without* IOUS. The primary end point was the incidence of any graft-related complication or death. Secondary end points included the incidence of each specific graft-related complication and the incidence of graft-related death. Graft-related complications were graft thrombosis, restenosis (>70%), recurrent symptoms, and (endovascular or open) visceral reintervention. *Early perioperative period* was defined as occurring within 30 postoperative days or within the hospital stay without regard to the number of days after the operation it occurred. Graft patency was defined according to the suggested standards and was assessed objectively by imaging studies.[13] In general, a noninvasive study was performed prior to dismissal or within the first 6 postoperative weeks and yearly thereafter. Patients with symptomatic restenosis were referred for angiography. Clinical and radiologic follow-up was the same for patients with normal and abnormal ultrasound scans.

Statistical analysis. Survival and graft patency curves were calculated by the Kaplan-Meier method. Differences were determined by the log-rank test. For analysis of categorical variables, the χ^2 and Fisher exact test were used. Differences between means were tested with the Mann–Whitney *U* test. Univariate analysis to assess the independent effects of variables on clinical outcome was done with the Cox proportional hazard method. A *P* value <.05 was used to determine statistical significance.

Table II. Intraoperative ultrasound findings in patients who underwent visceral revascularizations

Ultrasound classification	*n = 120*	*%*
Normal	102	85
Abnormal	18	15
Minor defects*	8	6.6
Mild kinking	4	3.3
Mild residual stenosis	3	2.5
Small intimal flap	1	0.8
Major defects	10	8.4
Severe residual stenosis	3	3.3
Thrombosis	2	1.7
Severe kinking	2	1.7
Severe residual plaque	1	0.8
Bi-directional flow	1	0.8
Dissection†	1	0.8
Large intimal flap	1	0.8

* *Minor defects* were defined as nonhemodynamically significant abnormalities (peak systolic velocity of less than 2.0 m/sec for the celiac, less than 2.75 m/sec for the superior mesenteric artery, and velocity ratio of less than 2.0).
† *Dissection* was noted after thromboembolectomy in one patient with graft thrombus.

RESULTS

Clinical characteristics. There were 68 patients (15 men and 53 women) with a mean age of 66.5 years (range, 27-86 years). Operative indications for visceral revascularization were chronic atherosclerotic mesenteric ischemia in 60 patients (88%), arcuate ligament syndrome in 4 patients (6%), visceral arterial aneurysms in 2 patients (1 celiac and 1 celiomesenteric trunk aneurysm), and acute mesenteric ischemia in 2 patients (3% each). Clinical characteristics in patients with chronic mesenteric ischemia are summarized in Table I.

Initial operative treatment. All procedures were performed under general endotracheal anesthesia using either

the transabdominal (93%) or the retroperitoneal approach (7%). Fifty-seven patients underwent visceral bypasses (bifurcated graft, 44; interposition graft, 13), 7 had endarterectomy, and 4 had medial arcuate ligament release, 2 with patch angioplasty. The most common procedure was a supraceliac aorto-celiac-SMA bypass in 44 patients (65%). Forty-eight patients had antegrade, and 9 had retrograde graft configuration. Adjunct arterial procedures performed as part of the bypass procedure were used in 17 patients, including focal endarterectomy at the distal anastomosis (9), branch reimplantation (5), and patch angioplasty (4). Six patients underwent combined visceral and renal arterial revascularizations, two had concomitant aortic replacement, two had aortic endarterectomy, and one had a femoral interposition graft.

Intraoperative ultrasound findings. A total of 120 visceral arteries were revascularized (52 celiac, 60 superior mesenteric, and 8 inferior mesenteric arteries) and evaluated with IOUS (Table II). One hundred and two (85%) arteries yielded normal ultrasound scans. In normal arteries, mean PSV was 1.5 m/sec (range 0.2-3.6) for celiac axis and 1.6 m/sec (range 0.3-3.0) for SMA. Thirteen (10.8%) vessels had nonfocal velocity elevation due to graft-vessel mismatch (mean PSV, 2.1 m/sec). Eight (6.6%) arteries had minor defects, including four mild graft/vessel kinks, three mild residual stenoses, and one small intimal flap. None of these defects was suspected clinically. In arteries with minor defects, mean PSV was 1.8 m/sec (range, 0.8-3.0) for celiac axis and 2.1 (range, 1.7-3.1) for SMA. Ten (8.4%) arteries had major defects. The most common major abnormality was severe residual stenosis (4), followed by thrombus (2), kink (2), bidirectional flow (1), and intimal flap (1) (Fig 2). In arteries with major defects, mean PSV was 2.9 m/sec (range, 1.0-3.6) for celiac axis and 3.0 m/sec (range, 1.2-4.0) for SMA. Electromagnetic flow measurement (Carolina Medical Electronics, King, NC) averaged 805 mL/sec (range, 260-2000) in normal arteries, 755 mL/sec in arteries with minor defects (range, 420-900), and 650 mL/sec in arteries with major defects (range, 100-1400). Of the ten arteries with major defects, three were suspected clinically because of weak pulse (1) or exceedingly low (<200 mL/sec) graft flow (2).

Immediate operative revision. Minor defects were not revised. All ten major defects prompted immediate operative revision, which confirmed the presence of intraluminal abnormalities in nine occasions. One patient had bidirectional flow with more significant flow toward the aorta after aorto-SMA bypass; there was no underlying technical abnormality to account for this finding. Major defects were repaired by means of anastomotic revision (4), thrombectomy (3), patch angioplasty (3), removal of residual plaque (1), tacking sutures (1), resection of residual intimal flap (1), and resection of redundant artery (1). Postrevision ultrasound scan revealed six normal revascularizations, two mild residual stenoses, one bidirectional flow, and one dissection. With the exception of the dissection, the other defects were left unrepaired.

Early outcome. The operative mortality was 4.4% (3/68). All three deaths occurred in patients operated for chronic mesenteric ischemia. Two patients (3%) died of multiorgan failure associated with early graft thrombosis. The first patient had normal IOUS after aortic and visceral endarterectomy, but developed thrombosis of the celiac, SMA, inferior mesenteric (IMA), and right renal arteries on the first postoperative day. There were no technical abnormalities at time of emergent thromboembolectomy. Despite intensive medical therapy, the patient expired 48 days later without evidence of ongoing ischemia or recurrent thrombosis. The second patient thrombosed an aorto-celiac-SMA bypass, which had a small unrepaired intimal flap at the distal celiac anastomosis. Because of this persistent abnormality and chronic occlusion of the common hepatic artery, we believe the thrombus originated in the celiac axis and extended into the SMA limb. The patient expired shortly after re-exploration. A third patient had a fatal myocardial infarction on postoperative day 12. This patient had a large intimal flap after visceral endarterectomy, which was successfully repaired. At the time of his death, there was no evidence of graft thrombosis.

The mean length of stay was 12.7 days (range, 4-48 days). Dismissal imaging studies were obtained in 28 patients (44%) and included 24 intravenous digital subtraction angiographies (IVDSA), 10 duplex ultrasound scans, and 6 magnetic resonance angiographies (MRA); all imaged revascularizations were patent. There was one moderate (<70%) SMA stenosis in a patient with unrepaired SMA kink. Overall, there were three early graft thromboses (2.5%), two of which were fatal (previously described). A third patient underwent aorto-SMA bypass and had a major residual stenosis at the distal anastomosis. After immediate revision, repeat IOUS revealed persistent mild stenosis, which was not revised. This patient had graft thrombosis with bowel ischemia, requiring thromboembolectomy and jejunal resection. Despite an uneventful hospital course, the patient died of exsanguinating intra-abdominal hemorrhage 5 months after dismissal, presumably from graft infection and/or disruption.

Late outcome. The median clinical follow-up was 3.1 years (range, 6 months-10.6 years). Late follow-up was complete in all but two patients. Symptoms of recurrent mesenteric ischemia developed in four patients (6%) and included abdominal pain in four, nausea and vomiting in two, and diarrhea in one. One patient required long-term TPN for short bowel syndrome. Objective follow-up was obtained in 53 patients (81.5%) and 91 visceral arteries. Ten patients (17.8%) in the normal and two (22.2%) in the abnormal ultrasound group had no imaging studies. Follow-up imaging studies included duplex ultrasound scanning in 42 patients (65%), selective visceral angiography in 7 patients (11%), and MRA in 6 patients (9%). Late studies showed 82 patent grafts (90%), 3 moderate (<70%) asymptomatic graft restenosis (3.2%), and 6 severe (>70%) graft restenosis, 4 of which led to recurrent ischemic symptoms requiring reintervention. One asymptomatic and two symptomatic restenosis occurred in the abnormal IOUS

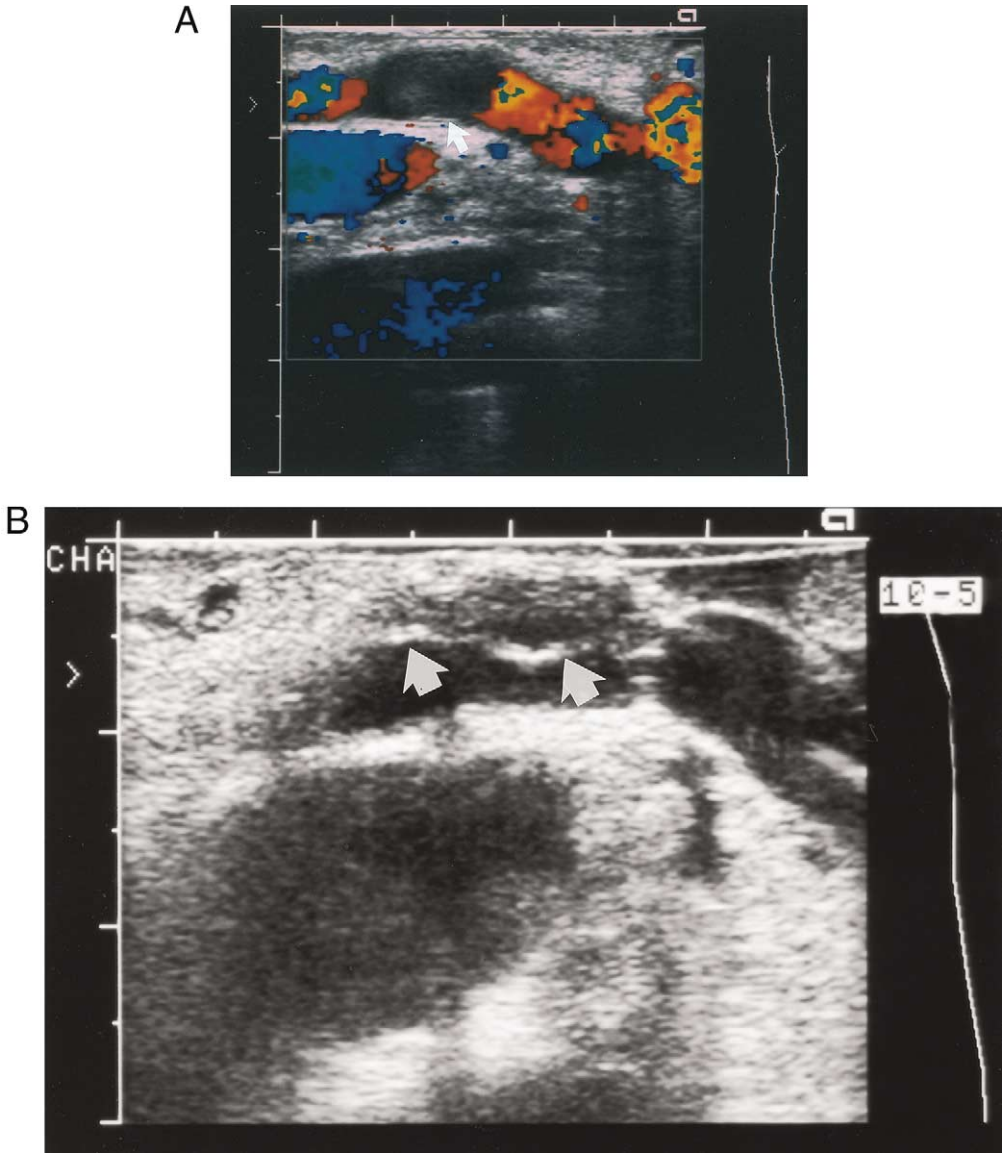

Fig 2. Color Doppler images reveal occlusive thrombus in the proximal common hepatic artery after aortoceliac-SMA bypass (**A,** *small arrow*). After thromboembolectomy, gray-scale sonogram demonstrates an intraluminal flap consistent with dissection (**B,** *large arrows*). Resection of the dissected intima and patch angioplasty resulted in normal repeat ultrasound.

group. Symptomatic restenoses were treated with percutaneous transluminal angioplasty (PTA) in three patients and stenting in one patient. Overall, the cumulative primary patency rate was 94% and 90% at 1 and 5 years, respectively. The cumulative secondary patency rate was 98% and 96% at the same intervals, respectively.

The cumulative survival rates at 1 and 5 years were 86% and 61%, respectively. Late deaths (18 of 65) were result of cardiac event (7), cancer (3), massive gastrointestinal bleeding (1), intra-abdominal hemorrhage (1), chronic malnutrition (1), or unknown causes (5). Two late deaths were possibly associated with graft-related complications. The first patient died of exsanguinating intra-abdominal hemorrhage (previously described). The second patient underwent aorto-SMA bypass and had persistent residual stenosis despite revision of a major stenosis. The patient died a year later from malabsorption and chronic malnutrition.

Factors associated with graft-related complications. Univariate analysis was used to identify factors associated with graft-related complications and/or death. (Table III). A positive association was found for abnormal IOUS (55.5% vs 7.8%; $P = .004$) and single-vessel revascularization (35.7% vs 10.8%; $P = .04$). Multiple regression logistic

Table III. Univariate analysis of variables associated with risk of any graft-related complications and/or death in patients who underwent visceral revascularization for chronic mesenteric ischemia with IOUS

Variable	*Graft-related complication/death (%)*		P
	With variable	*Without variable*	
Abnormal ultrasound	55.5	7.8	0.004
Single-vessel revascularization	35.7	10.8	0.04
Low flow (<500 mL/sec)	27.1	10.5	0.12
Redo-revascularization	100	15.8	0.16
Retrograde bypass	22.2	11.8	0.16
Coronary artery disease	25.0	11.1	0.17
Age > 70 years	24.1	9.7	0.17

Other variables, including male gender ($P = 0.32$), hypertension ($P = 0.47$), diabetes ($P = 0.11$), hyperlipidemia ($P = 0.73$), renal failure ($P = 0.52$), and tobacco use ($P = 0.58$), were not associated with increased risk of graft-related complications/death.
IOUS, Intraoperative duplex ultrasound scanning.

analysis identified abnormal IOUS as the only independent risk factor for graft-related complication and/or death (odds ratio, 7.08; 95% confidence interval, 1.65 to 30.4; $P = .008$). Although percentages of graft-related complications were higher in patients without IOUS, differences were not significant: any graft-related complication/death (22% vs 15%), early graft thrombosis (5.4% vs 2.7%), mesenteric ischemia (9.4% vs 5%), late restenosis (7.8% vs 4.8%), and visceral reintervention (7.8% vs 6.4%). Clinical outcome in patients with chronic mesenteric ischemia is summarized in Table IV.

DISCUSSION

Intraoperative assessment of arterial reconstructions has always been sought by vascular surgeons as a means to detect technical imperfections that can adversely affect outcome. This is particularly true for visceral revascularizations, where unrecognized technical errors may lead to graft failure, bowel necrosis, and significant morbidity. Historically, several methods have been used to evaluate the adequacy of arterial reconstructions. Direct visual inspection, pulse palpation, continuous-wave Doppler signal analysis, arterial pressure measurements, and electromagnetic flow measurements are rapid, safe, and easy to perform, but they lack sensitivity and cannot localize intraluminal defects. Although angiography can accurately detect small intimal abnormalities, it carries the disadvantages of being more invasive, adding radiation exposure, and potentially causing arterial injury, embolization, or contrast-induced toxicity. Conversely, intraoperative duplex ultrasound scanning has distinct advantages over these techniques. It is safe, noninvasive, expeditious, and provides both anatomic (gray-scale) and hemodynamic (spectral analysis) information with very high sensitivity, specificity, and negative predictive rates.[1-11]

This study supports the routine use of intraoperative duplex ultrasound scanning during visceral revascularizations. However, some potential limitations of our study design merit discussion. The relatively high incidence of major technical defects (8.4%) may be partially explained by selection bias from a nonconsecutive series of patients. It is possible that early in our experience surgeons were more likely to use intraoperative ultrasound scanning if they were suspicious of a technical problem. Similarly, selection of "higher risk patients" may have accounted for an increased incidence of complications in comparison to other series. Several limitations are inherent from retrospective design and small study population, including possible type II error. Because visceral graft thrombosis is often an asymptomatic occurrence, it is possible that we have underestimated the incidence of late graft failure in patients without follow-up studies.

In an effort to classify patients in an unbiased fashion, radiologists were blinded to the intraoperative interpretation or clinical outcome. However, because actual videotapes were not reviewed, it is possible that some arterial abnormalities not documented on hard copies were missed. Similarly, because hard copies contained a different number of images per patient and no standard protocol was used, it is possible that studies with fewer images seemed less suspicious than studies with multiple images. In addition, because major defects were very well documented, it is not surprising that there was no disagreement between the study radiologist and initial interpretation. However, we believe the fact that our studies were performed by a staff radiologist minimized the chance of suboptimal ultrasound scans or missed lesions. Finally, the velocity criteria used in this study should be carefully analyzed, as validated criteria are available for native arteries but not for visceral bypasses.[12] We are aware that factors such as graft diameter, length, and characteristics of the target artery impact velocity measurements. This may well explain the high incidence of nonfocal velocity elevation due to graft-vessel mismatch. Without velocity criteria validated for visceral bypasses, we emphasize the importance of using the velocity ratio to identify hemodynamically significant arterial abnormalities.

A major requirement for any intraoperative arterial monitoring technique is the ability to accurately identify technical abnormalities. In our study, electromagnetic flow measurement did not predict the presence of major defects. In fact, only three of ten major defects had flow limiting lesions (<500 mL/sec), including one bidirectional flow (140 mL/sec), one residual stenosis (<100 mL/sec), and one graft thrombus (400 mL/sec). One patient with thrombus and dissection had excellent flows (1400 mL/sec). Although flow measurement provides useful information about the graft/vessel hemodynamics, we believe that one cannot relay on absolute numbers to rule out technical defects.

Other relevant factors in selecting the ideal monitoring technique are availability, time requirement, learning curve, and cost. Reluctance to use intraoperative ultrasound scanning has been attributed to expense, cumbersome technique, difficulty interpreting ultrasound scan findings, and the false belief that clinical examination alone

Table IV. Comparison of clinical outcome in patients with normal IOUS, abnormal IOUS, and no IOUS during visceral revascularization for chronic mesenteric ischemia

	*IOUS**					*No IOUS**		
	Normal		*Abnormal*					
Clinical outcome	*n = 51 (95 vessels)*	*%*	*n = 9 (14 vessels)*	*%*	P[1]	*n = 32 (56 vessels)*	*%*	P[2]
Early complication								
Thrombosis	1	1.0	2	14.2	0.04	3	5.4	0.14
Mesenteric ischemia	1	1.9	2	22.2	0.05	3	9.4	0.29
Late complication								
Thrombosis	0	0	0	0	—	0	0	—
Restenosis	3	3.2	2	18.2	0.08	4	7.8	0.24
Recurrent ischemia	2	4.0	1	14.3	0.32	1	3.4	1.0
Visceral reintervention†	3	3.2	3	21.4	0.03	4	7.8	0.24
Graft-related death†	1	1.9	3	33.3	0.02	2	6.3	0.56
Any complication/death†	4	7.8	5	55.5	0.009	7	22.0	0.1

*Clinical outcome in patients with normal IOUS was compared to that in patients with *abnormal IOUS* (P^1) or *no IOUS* (P^2). The total number of vessels was used for analysis of graft thrombosis, restenosis, and reintervention.
†Includes early and late visceral reintervention, graft-related death, and any complication/death.
IOUS, Intraoperative duplex ultrasound scanning.

provides accurate information about the adequacy of arterial reconstructions. Considering that the sensitivity of pulse palpation, direct visualization, and flow measurement are unacceptably low, it seems obvious that another method of intraoperative monitoring is necessary. With the uniform availability of newer generation duplex scanners, the validity of these concerns must be questioned. In our experience, intraoperative ultrasound scanning is the most expeditious method to evaluate visceral revascularizations and does not increase operative time, even on complex cases. Ultrasound scanning is less expensive than completion angiography, and it provides anatomic and hemodynamic information. To facilitate the interpretation of ultrasound scan findings and eliminate unnecessary revision of "insignificant" abnormalities, the combination of gray-scale scanning and real-time Doppler spectral analysis identifies defects that are hemodynamically significant. Although the current study did not evaluate the sensitivity and specificity of duplex ultrasound scanning during visceral revascularizations because confirmatory studies (angiography) were not done, we believe that intraoperative ultrasound scanning has the same excellent performance in the visceral circulation.

Does detection of technical defects prevent graft failure after visceral revascularizations? Although the study had no power to demonstrate improved outcome in patients who had revascularization with intraoperative ultrasound scanning in comparison to those who had no ultrasound scan, the presence of persistent technical abnormality seems to be associated with increased graft-related morbidity and mortality. However, although two of the three early graft thromboses occurred in patients with abnormal ultrasound scans, one patient had graft thrombosis after a technically flawless visceral endarterectomy, indicating that some failures may reflect factors associated with increased vessel thrombogenicity or hypercoagulable states, rather than the presence of technical defects.

The next logical question is whether one should accept nothing but a technically perfect revascularization? No one argues that all major defects should be immediately repaired. However, the ideal management of "minor defects" remains uncertain. Unfortunately, in addition to several study limitations previously discussed, other factors complicate the interpretation of available data. First, the incidence and impact of arterial defects probably varies with type of reconstruction (eg, in situ graft, endarterectomy), vessel caliber, hemodynamic characteristics, and patient-related factors (eg, hypercoagulability, postoperative hypotension). Second, technical defects are heterogeneous in nature and probably have a different impact on clinical outcome; a small intimal flap or dissection may portend a more ominous risk of thrombosis than a mild stenosis or vessel tortuosity. Lastly, the definition of *significant abnormality* is somewhat unclear in the literature, which limits comparison between studies. However, several other reports have shown an increased incidence of early and late graft failure in patients with technically imperfect revascularizations.[3-4,8-10] Although we currently advise a very low threshold to repair "minor" defects, patients should be treated on an individual basis and clinical judgment ultimately dictates the need for immediate revision.

In summary, visceral revascularization is currently performed with significantly less morbidity and mortality than 20 years ago.[14] Despite advances in modern vascular surgery, technical imperfections continue to occur and may be unrecognized without intraoperative monitoring. Considering all factors, intraoperative duplex ultrasound scanning provides a safe, accurate, and practical modality to evaluate the adequacy of arterial reconstructions. We currently obtain intraoperative duplex ultrasound scanning on most

patients undergoing carotid, renal, and visceral revascularizations. We believe that the detailed anatomic and hemodynamic information provided by duplex scanning allows better interpretation of the severity of the defect. We advocate immediate revision of all major defects followed by repeat intraoperative ultrasound scanning to document resolution of the arterial abnormality. Although the ideal management of minor defects remains unclear, our study favors having a low threshold to repair these lesions in the visceral arteries. Finally, patients with normal ultrasound scanning findings, either on initial examination or after revision of major defects, can expect excellent early and late outcome after visceral revascularization.

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